

Measuring Infant Learning: A Novel Paradigm Utilizing End-Point Controlled Movements

Madelaine Driskill

Driskill.13@buckeyemail.osu.edu

Biomedical Science Undergraduate Major

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Senior Project Advisor: Dr. Jill Heathcock, Ph.D.
Assistant Professor, The Ohio State University
College of Medicine, School of Allied Medical Professions
Division of Physical Therapy
516 Atwell Hall
453 W. 10th Avenue
Columbus, OH 43210
Phone: (614) 292-2397
Email: jill.heathcock@osumc.edu

Second Project Advisor: Dr. Allison Lane, Ph.D.
Assistant Professor, The Ohio State University
College of Medicine, School of Allied Medical Professions
Division of Occupational Therapy
406-C Atwell Hall
453 W. 10th Avenue
Columbus, OH 43210
Phone: (614) 292-0204
Email: lane.350@osu.edu

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Abstract

Introduction: The rate of preterm births is increasing and with developments in neonatal and obstetric care, more preterm infants are surviving. These infants are at risk for both motor and cognitive delays. With earlier diagnosis, earlier interventions can be performed to mediate problems in the preterm infant population. Motor and cognitive disorders, however, are difficult to diagnose in infancy. Currently, the Mobile Paradigm (MP) is used to test infant learning. This paradigm uses spontaneous movements to assess infant learning. The goal of this project is to develop a new method of testing infant learning and memory that uses end-point controlled movements that can be used in a clinical setting to diagnose cognitive delays in preterm infants as well as other infants at risk for delay. *Population:* Six infants between the ages of 3 and 6 months participated in this study. All infants were full-term except one, who was born at 33 weeks gestation. *Methods:* Five infants were tested using both the MP and a new end-point controlled paradigm called the Touch Screen Paradigm (TSP). One infant was excluded from the MP due to rolling over. In each paradigm, three phases were tested: Baseline, Acquisition, and Extinction. The Baseline phase measured the infant's typical behavior. During the Acquisition phase, reinforcement was given for a desired behavior so the infant acquires the desired behavior. During the Extinction phase, no reinforcement was given. An increase in the desired behavior during the Acquisition or Extinction phases as compared to the Baseline phase indicates the infant learned the association between desired behavior and reinforcement. All testing sessions were video recorded and analyzed. *Results:* On average, the infants demonstrated learning during the TSP and the MP. Individually, all infants demonstrated learning during the MP and four showed learning during the TSP. *Conclusions:* The TSP shows promise as a clinical tool to diagnose cognitive disorders and problems with learning in infancy. More infants need to be tested with this new paradigm to confirm validity.

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Chapter 1

Problem Statement

Infants at risk for developmental delays

The mortality rate of preterm infants is decreasing due to medical advances in neonatal, obstetrics, and pediatric care, so more preterm infants that are at risk for delay are surviving (Alexander, Kogan, Bader, Carlo, Allen, & Mor, 2003). In Ohio, on average, 372 babies are born preterm (<37 weeks gestation) and 60 babies are born very preterm (<32 weeks gestation) each week (March of Dimes, 2009). In 2005, 14.1% of babies in Columbus were preterm (March of Dimes, 2009). In 10 years, from 1995 to 2005, the rate of preterm births in Ohio increased 16% (March of Dimes, 2009). The national preterm birth rate in the United States in 2006 was 12.8%, compared to 11.0% in 1996 (March of Dimes, 2009). Worldwide, 13 million infants are born preterm each year, which accounts for about 10% of all births (March of Dimes, 2009). The problem of preterm birth is significant on a local, national, and international level. More preterm infants are born and more are surviving who are at risk for developmental delay that can negatively influence learning and memory capacity (Cherkes-Julkowski, 1998; Drummond & Colver, 2002). Preterm infants show a higher rate of many disabilities including cerebral palsy (Han, Bang, Lim, Yoon, & Kim, 2002), learning problems (Alexander et al., 2003), poor hand-eye coordination and developmental dyspraxias (de Vries & Groot, 2002). Preterm infants weighing less than 3.33 pounds are 20 to 80 times more likely to develop cerebral palsy, which is typically not diagnosed until age 2 or 3 (March of Dimes, 2009).

Preterm infants require an increased number of resources such as counseling, learning

resources in school like special education, physical therapy, and occupational therapy compared to full-term infants. This increased need can have a significant financial toll on families and their communities, totaling \$26.2 billion in societal economic cost in the United States in 2005 (March of Dimes, 2009; Saigal, Hoult, Streiner, Stoskopf, & Rosenbaum, 2000).

Previous Research on Preterm Infants

Once preterm infants enter childhood, developmental delays are commonly diagnosed (Sommerfelt, 1998), but during infancy, problems with cognition and movement can be attributed to a number of factors, so specific diagnoses are difficult (Alexander et al., 2003; Drummond & Colver, 2002; Hutton, Pharoah, Cooke, & Stevenson, 1997). Recent research also indicates that even in the absence of major neurological and medical complications, preterm infants can still display learning and memory difficulties (Gekoski, Fagen, & Pearlman, 1984; Rose, Feldman, & Jankowski, 2001). Therefore, it is possible that preterm infants will display learning and memory problems during infancy. By evaluating the interaction an infant has with their surroundings, an infant's ability to learn, move, and remember can also be evaluated (Siagal, 2000; Torrioli, Frisone, Bonvini, Luciano, Pasca, Lepori, Tortorolo, & Guzzetta, 2000). In kicking, and learning and memory studies, preterm infants have fewer spontaneous movements and do not demonstrate learning or memory of a cause-and-effect relationship (Heathcock, Bhat, Lobo & Galloway, 2004). In a paradigm used to test infant cognition, the Mobile Paradigm (MP), full-term infants learn a cause-and-effect relationship easily in 15 minutes and remember it for up to one week (Heathcock et al., 2004). Preterm infants, however, do not learn this

association, even with repeated testing (Heathcock et al., 2004). The MP uses spontaneous movements – specifically kicking – to test learning and memory. If preterm infants have fewer spontaneous kicking movements, as demonstrated in other studies, they will not learn cause-and-effect relationships with the methods used in the MP. Interestingly, preterm infants can reach out with their feet to touch a toy (Heathcock, 2006). This research analyzes the effectiveness of a novel paradigm in testing infant cognition, the Touch Screen Paradigm (TSP). The TSP combines a standard learning paradigm (Baseline, Acquisition, Extinction) with a skill that preterm infants seem to be able to perform, feet reaching, in order to determine if poor performance in the mobile paradigm is a learning issue or coordination issue.

The overall goal of this project is to design a complementary method of testing infant learning that uses end-point controlled movements rather than

spontaneous movements. This paradigm will be called the Touch Screen

Paradigm (TSP). In addition, a long-term goal of this project is to determine if preterm infants' poor performance in the mobile paradigm is due to an inability to learn and remember cause-and-effect relationships or if it is due to problems in underlying motor skills. End-point controlled movements are motions in which the subject moves the end-point, the foot, towards a specific point in an attempt to touch or reach it. In the mobile paradigm, preterm infants demonstrate neither learning nor memory (Heathcock et al., 2004) Preterm infants do, however, show an ability to contact a toy with their feet (Heathcock, 2006). The methods of this study can be performed on preterm infants to determine if their poor performance in the mobile paradigm is due to a lack of spontaneous kicking movements or cognitive deficits.

Diagnostic tool

This paradigm and procedure were tested on both preterm and full-term infants. This paradigm proved promising in determining an infant's ability to learn. Once problems with the paradigm are mediated, this paradigm can be used as a diagnostic tool in conjunction with other tools such as imaging to diagnose developmental delays in preterm infants and other infants at risk for delay. This protocol could be used to measure associative learning and memory in infants at risk for developmental delay.

Review of Literature

Learning cause-and-effect relationships is a characteristic of infant development. Parents report that infants cry differently when they are hungry or after they have seen a bottle (Freud, 1954). Commercial infant toys require the infant to produce an action, whether that be a reach with the hands or a kick with the legs, to result in reinforcement such as a light, noise or texture from the toy. In experimental settings, learning these cause-and-effect relationships can be tested. For example, infants who are one-month-old will suck more on a nipple when their mother's voice plays in the background (Mehler, Bertoncini, Mehler, Barrière & Jassik-Gerschenfeld, 1978). In addition, older babies learn in one day how to pull a joystick to make a small cart move forward in order to move closer to their mother (Galloway, Ryu, & Agrawal, 2008). Preterm infants have difficulty learning similar cause-and-effect relationships (Heathcock et al., 2004). Therefore, this project will begin to investigate one reason why preterm infants might have delays learning cause-and effect relationships.

Motor skills are also a characteristic of infant development. Babies follow a traceable progression of basic motor skill development such as rolling to crawling to walking (Piek, 2006). In an experimental setting, motor skill development can be tested.

As such, we know that there are several underlying motor skills such as kicking, reaching and postural control that affect how and when infants learn these basic skills such as crawling and walking (Piek, 2006). Preterm infants show delays in basic motor skill development (Piek, 2006). Interestingly, preterm infants also have difficulty with underlying motor skills (Piek, 2006). They show poor coordination during kicking and reaching and have poor postural control (Piek, 2006). Therefore, this project will begin to investigate the developmental progression of an underlying motor skill in preterm infants.

The population of preterm infants is rising (March of Dimes, 2009). These infants are at risk for developmental disabilities such as cerebral palsy and learning disabilities (Nelson & Ellenberg, 1985). Cerebral palsy is not identified until 2 to 3 years of age, when infants show significant delays in basic motor skills (Sankar & Mundkur, 2007). Learning disabilities may not be identified until the child can talk. One reason is that underlying motor skills and learning disabilities are difficult to identify during infancy. This project aims to fill this gap and identify poor motor and learning behaviors in an infant population.

As a result, this project is the first to combine an underlying motor task that incorporates controlled movement rather than spontaneous movement and learning in order to test the abilities of infants.

I. Operant Conditioning

Operant conditioning is defined as the modification of a behavior through the use of consequence. As opposed to classical conditioning, operant conditioning pertains to voluntary movements rather than reflexes. In order to change the frequency of a behavior, reinforcement and punishment are used (Domjan, 2003).

Reinforcement increases the frequency of the emitted response, whereas punishment decreases the frequency (Gerirtz & Pelaez-Nogueras, 1992). Reinforcements can be positive, in which a desired stimulus is presented, or negative, in which an undesired stimulus is removed. The Baseline frequency is the frequency of the emitted response when uninfluenced by reinforcement or punishment. Acquisition occurs when the emitted behavior is performed due to reinforcement or punishment. Extinction occurs when the reinforcement or punishment is removed, causing the emitted response to eventually go away. Initially, however, the frequency of the behavior is increased during Extinction, called an Extinction burst (Fig. 1) (Domjan, 2003). The principles of operant conditioning will be applied to this study.

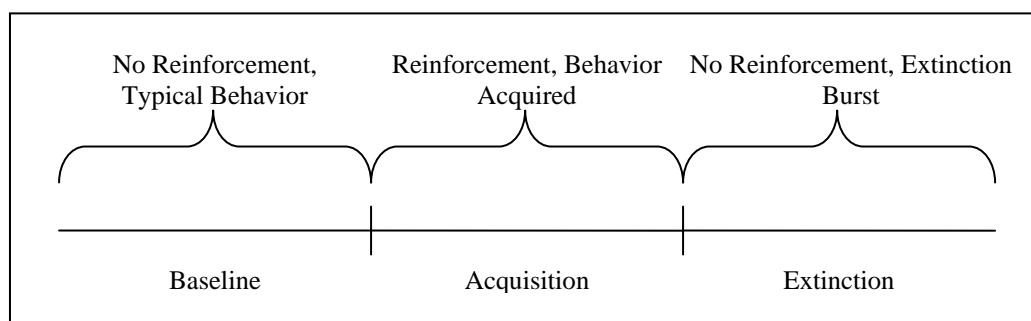


Figure 1. Phases of operant conditioning.

II. Mobile Paradigm

The Mobile Paradigm (MP) has been used for the past 35 years to analyze the learning and memory abilities of infants between the ages of 2 and 6 months (Rovee, C. & Rovee, D., 1969; Rovee-Collier, Hayne, & Colombo, 2001). In the MP, the infant is in the supine (lying down with the face up) position with one leg tethered to a mobile above their head. When the tethered leg kicks, the mobile

moves proportionally to the movement of the leg. The mobile movement is the reinforcement for kicking. Learning is evident when the kicking rate during the Extinction phase is elevated in comparison to the kicking rate during the Baseline phase. Short-term memory is evident when the Baseline kicking rate during day 2, one day after day 1, is increased in comparison with the kicking rate during day 1. Long-term memory is evident when the Baseline kicking rate during day 3, one week after day 1, is increased in comparison with the kicking rate during day 2. In the MP, typically developing infants (full-term infants with no known disease or developmental problem) demonstrate learning, short-term and long-term memory, whereas preterm infants demonstrate neither (Heathcock et al., 2004). In this project we will test learning only.

Objectives: Specific Aims and Hypotheses

The new paradigm, the Touch Screen Paradigm (TSP), will use end-point controlled movements rather than spontaneous movements to test infant learning. In the TSP, the infant will touch a target on a computer touch screen and receive visual and auditory reinforcement for doing so. Data will be analyzed on the group and individual level.

Three specific aims will be incorporated into this project.

Aim I: To determine an infant's ability to learn to reach for a target with their foot. We hypothesize that infants will demonstrate the ability to learn to touch the target with their foot. This hypothesis is supported by typically developing infants' performance in the mobile paradigm, in which they demonstrate the ability to learn (Heathcock et al., 2004).

Aim II: To compare the effectiveness of the TSP as compared to the MP in measuring an infant's ability to learn.

We hypothesize that typically developing infants will demonstrate the ability to learn to touch the target with their foot as well as the association between mobile movement and kicking with the right foot.

AIM III: To evaluate a computer program to be used in the TSP that accurately measures infant learning of the cause-and-effect relationship.

The TSP program will calculate the number of desired behaviors in each phase of testing. In addition, it will provide reinforcement for the desired behavior.

The overall goal of this project is to assess the feasibility of the TSP and determine if an operant conditioning paradigm using end-point control follows the anticipated progression of increased behavior from Baseline to Acquisition to Extinction periods. In addition, we hypothesized the effectiveness of the TSP and the MP and incorporated our hypotheses into one main hypothesis and two sub-hypotheses.

Hypothesis 1. The TSP and the MP will both effectively measure infant learning. .

Hypothesis 1.1. Infants will touch the target with their foot more frequently during Acquisition or Extinction than Baseline, indicating learning during the TSP.

Hypothesis 1.2. Infants will kick more during Acquisition or Extinction than Baseline, indicating learning during the MP.

An additional hypothesis that will be tested in the future is that preterm, as well as full-term, infants will demonstrate learning. This hypothesis is

supported by testing with preterm infants in which they showed an ability to touch a toy with their feet (Heathcock, 2006). In the case that preterm infants have a lack of spontaneous kicking in the mobile paradigm rather than impairments in learning, short-term memory, and long-term memory, this hypothesis will be supported.

Chapter 2

Methodology and Design

Six infants participated in this project. All infants completed the Touch Screen Paradigm (TSP) and five completed the Mobile Paradigm (MP). One infant was excluded from the MP for rolling over. The MP and the TSP were tested on different days within one week of each other. We tested three phases during each session. The first phase, Baseline, was three minutes long. During this phase, no reinforcement was given for the desired behavior. This phase showed the typical behavior of the infant. The second phase, Acquisition, was nine minutes long. In this phase, the infant acquired the desired behavior, either touching a target for the TSP or kicking with the right foot for the MP, and receiving reinforcement every time. The last phase, Extinction, was three minutes long. When the infant performed the desired behavior, no reinforcement was given, as in the Baseline phase (Fig. 1). An Extinction burst, where the frequency of the desired behavior increased, was expected based on the principles of operant conditioning. All visits were video recorded and the data was coded using operational definitions depending on the paradigm. The two paradigms, the MP and the TSP, are described in more detail below.

Mobile Paradigm (MP)

The MP was tested at each infant's home in the infant's crib. The infant was placed in the supine position with the right leg tethered to a mobile.



Figure 2. Mobile Paradigm set-up.

The mobile was attached to the infant's crib on one of two mobile stands. One stand was tethered to the leg such that when the infant kicked, the mobile moved. The other stand was not tethered, so when the infant kicked, nothing happened (Fig. 2). During the Baseline and Extinction phases, the mobile was attached to the non-tethered stand. When the infant kicked, no reinforcement was given. During the Acquisition phase, the mobile was attached to the tethered stand so that reinforcement was given when the infant kicked with the right leg. Videos of the testing sessions were reviewed and coded to determine the number and pattern of kicks. If an infant is consistently rolling from supine to prone, he/she cannot be tested in the MP. One infant was rolling over and so, could not be tested.

Touch Screen Paradigm (TSP)

During the TSP, infants sat in a custom-made infant seat at a 60° incline that allowed for free movement of the limbs (Fig. 3). A 17-inch computer monitor with a MagicTouch© touch screen attached was placed in front of the infant at a distance of 75% of the infant's leg length. This screen apparatus was secured to the base of the infant seat



Figure 3. Touch Screen Paradigm set-up.

using two c-clamps to prevent movement of the screen (Fig. 3). The computer monitor displayed a black-and-white checkered background with a red target in the center. During the Baseline and Extinction phases, nothing happened when the target was touched. During the Acquisition phase, when the infant touched the target, a 5-second video of a toy dog with a female voice saying, “Oh look!” played. The computer program recorded the coordinates (x, y) at which the infant touched the screen as well as the millisecond it was touched and if it was inside or outside the target. The computer data was analyzed. The testing sessions were also video recorded and reviewed to determine the number of times the target was touched. All babies were tested in the TSP.

Population and Sample

Five infants between the ages of 3 and 6 months were tested with the Mobile Paradigm (MP) and the Touch Screen Paradigm (TSP). One 6-month-old infant, MS, was only tested with the TSP because he was consistently rolling from supine to prone, which inhibits the MP. All babies were full-term except one, GD, who was born at 33 weeks gestation. For GD, we used corrected age, determining his age from his due date rather than his date of birth. Babies were recruited using newspaper advertisements, flyers, and word-of-mouth from around the central Ohio area.

Data and Instrumentation

Both the MP and TSP videos were analyzed by the same coder at a frame rate of 30 frames per second. For the TSP, the number of in-target touches was determined. A touch was operationally defined as any part of either foot making contact with the red target. If the infant rested his/her foot on the target, a new touch was not counted until the foot was

moved. This data was also collected using a computer program. For the MP, we determined the number of kicks and the pattern of kicks (alternating, parallel, foot rub or single). An alternating kick occurred when the infant kicked one leg immediately preceded or followed by a kick of the opposite leg. A parallel kick occurred when the infant kicked both legs together. A foot rub occurred when the infant put his/her feet together. A single kick was when the infant kicked one foot, but not the other. A *kick* was operationally defined as “a simultaneous extension of the hip and knee with immediate recoil into flexion. Hip and knee range of motion were not measured during kicking; however, we estimated a kick to include >15 degrees of simultaneous hip and knee extension” (Heathcock et al., 2004). For the MP analysis, we looked at the frequency of right leg kicking. The number of kicks and touches were determined for each testing session. The number was then averaged over the time period to determine the number of kicks or touches per minute.

Learning

Learning was operationally defined as having a target touching rate or a right leg kicking rate, during the Acquisition or Extinction period, greater than the Baseline of the same day.

Expected outcomes and interpretations: We expected infants would demonstrate learning based on performance in the mobile paradigm (Heathcock et al., 2004). To determine if learning occurred, we compared the target touching rate and the right-foot kicking rate of the infant during the Acquisition and Extinction phases with the Baseline rate during the same testing day. If the Acquisition or Extinction periods had

a greater touching rate or kicking rate than the Baseline rate of that day of testing, learning occurred.

Data Analysis

Data will be analyzed on both an individual and group level. Two ratios will be looked at, the Acquisition ratio and the Extinction ratio. The Acquisition ratio is defined as the rate of desired behavior during the Acquisition phase divided by the rate of the desired behavior during the Baseline phase. The Extinction ratio is defined as the rate of desired behavior during the Extinction phase divided by the rate of the desired behavior during the Baseline phase. The Extinction ratio, however, is a more powerful indication of learning because it indicates that the infant retained the association. The Acquisition ratio can be misleading if the baby performs the desired behavior more often during the Acquisition phase due to increased arousal from the stimulus, rather than learning the association. A ratio of greater than 1.5 indicates learning as defined in previous studies (Hayne, Rovee-Collier, C., & Perris, 1987). In addition, paired t-tests will be performed to compare Acquisition and Extinction to Baseline. A p-value of less than 0.05 indicates significance whereas a p-value of less than 0.10 indicates a trend.

Chapter 3

Results

In order to compare the MP and the TSP, we looked at group and individual performance in both paradigms. For individual data analysis, we used the manual coding performed by an undergraduate student in the Infant Lab in comparing the MP and the TSP. For the MP, we looked at frequency of right leg (tethered leg) kicks and for the TSP we looked at

frequency of in-target touching. If there is a missing data point, for example Extinction in MP for Baby GD, data was excluded due to the infant crying for more than two minutes.

Group Average

On average, the group of 6 infants demonstrated learning in both the MP and the TSP.

In both paradigms, kicking and touching rates increased during Acquisition and

Extinction (Fig. 4). Kicking rates increased from Baseline to Acquisition to

Extinction with 11.67 kicks/minute with a standard deviation of 5.75, 21.56 kicks/min

with a standard deviation of 9.61, and 35.42 kicks/minute with a standard deviation of

27.07, respectively (Fig. 4). Kicking rates ranged from 3.33 to 18.66 kicks/minute in

the Baseline phase, 10.22 to 31.44 kicks/minute during Acquisition, and 18.00 to

75.66 kicks/minute in the Extinction phase (Fig. 4). In-target touching rates also

increased from Baseline to Acquisition to Extinction with 4.11 touches/minute with a

standard deviation of 3.59, 7.65 touches/min with a standard deviation of 5.81, and

9.38 touches/minute with a standard deviation of 6.61, respectively (Fig. 4). In-target

touching rates ranged from 0 to 9.33 touches/min in the Baseline phase, 0 to 17.00

touches/minute in the Acquisition phase, and 0 to 15.60 touches/minute in the

Extinction phase (Fig. 4). In the TSP, Acquisition data demonstrated a trend of

increasing as compared to Baseline in a paired t-test ($p=0.10$). Extinction data showed

a significant increase in touching rate in a paired t-test ($p=0.039$). Both Acquisition

and Extinction data proved to have a significant increase in kicking rate for the MP in

paired t-tests ($p=0.019$ and $p=0.046$, respectively). Both paradigms followed the

expected progression of an increase in the desired behavior from the Baseline to the

Acquisition to the Extinction phases.

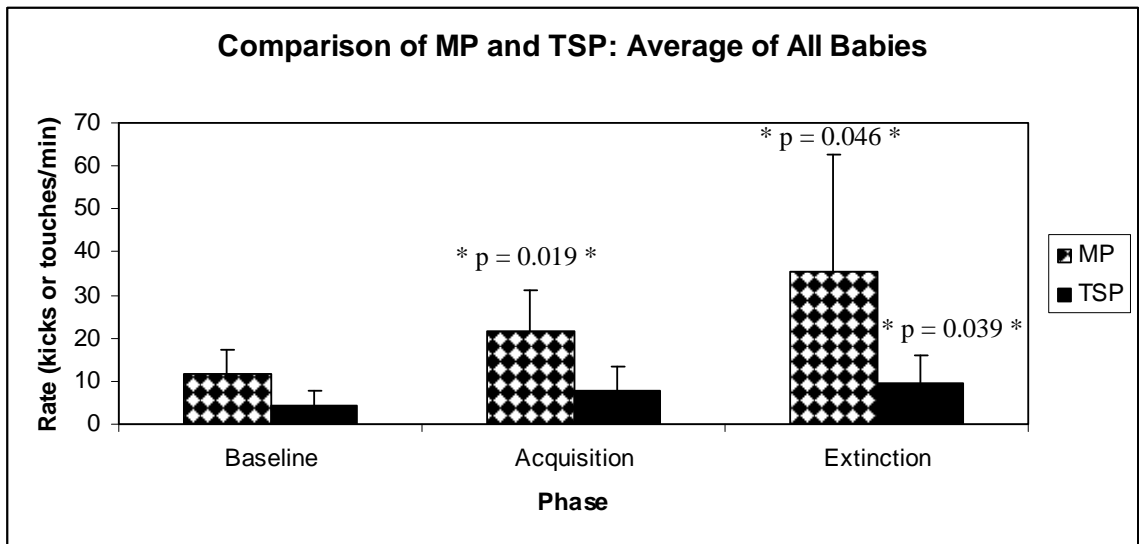


Figure 4. Comparison of MP and TSP, * indicates significance in paired t-test as compared to Baseline for that paradigm.

Baby AL

Baby AL demonstrated learning during both the MP and TSP. She also followed the expected progression of increased behavior from Baseline to Acquisition to Extinction (Fig. 5).

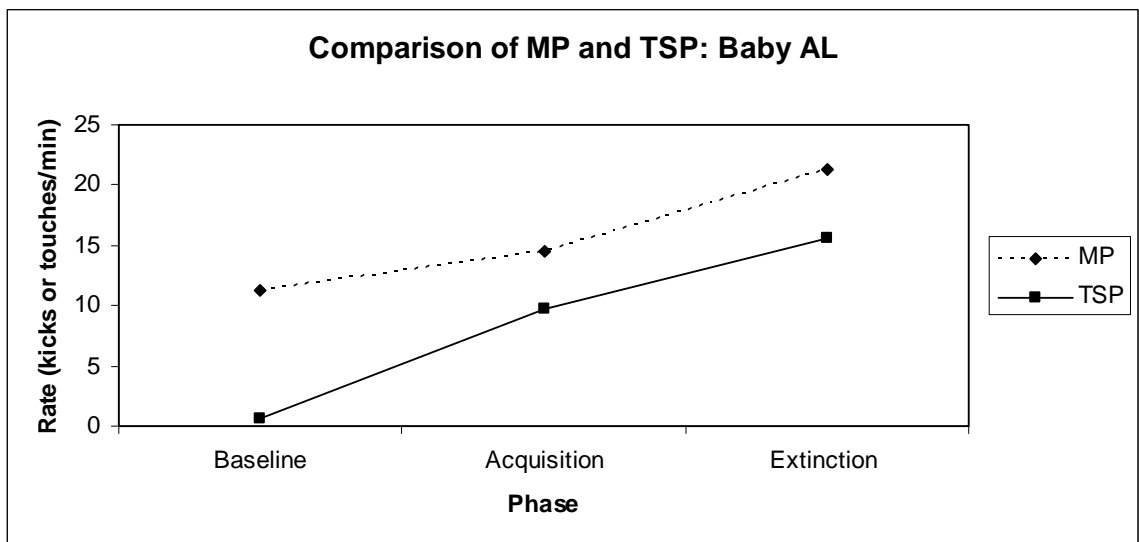


Figure 5. Comparison of MP and TSP for Baby AL.

Baby CM

Baby CM demonstrated learning in the MP, but not the TSP (Fig. 6). Even when the experimenter took her foot and placed it on the target to show what would happen, she did not increase her in-target touches.

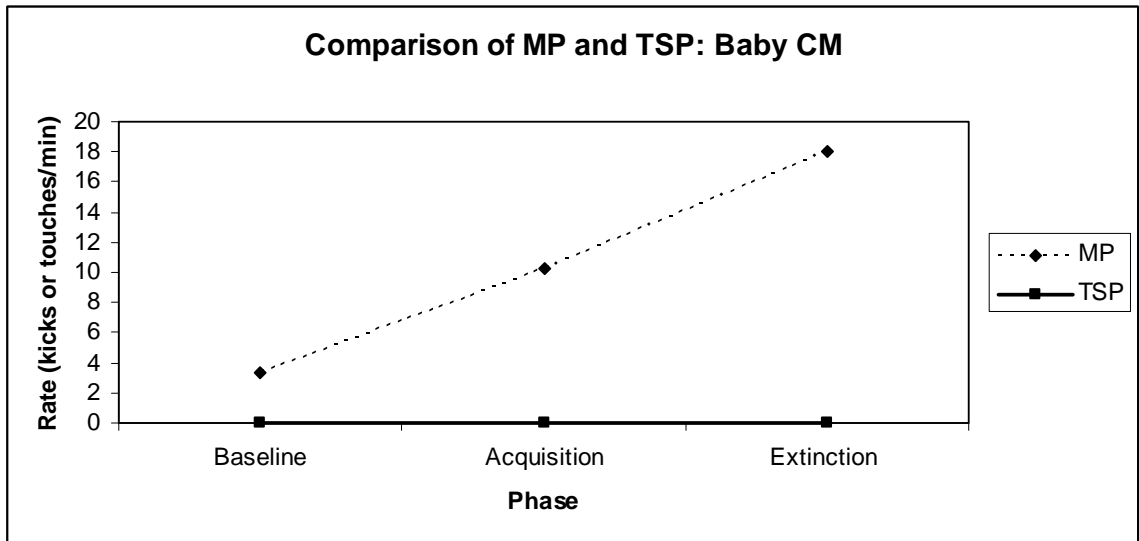


Figure 6. Comparison of MP and TSP for Baby CM.

Baby GD

Baby GD, the only preterm infant (33 weeks gestation) tested, showed potential learning in the MP, but not the TSP (Fig. 7). Due to crying, data was not collected during the Extinction phase of the MP. Since this data is missing, an Extinction ratio, the most important measure of learning, cannot be determined and so, learning in the MP for Baby GD cannot be measured. The data collected for Baby GD in the TSP is consistent with previous findings in MP for preterm infants.

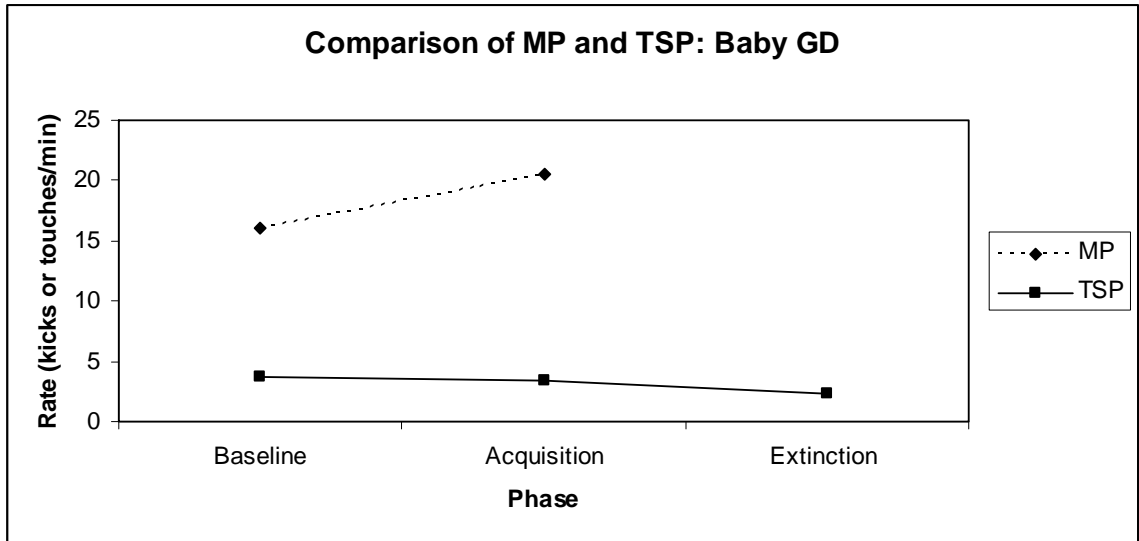


Figure 7. Comparison of MP and TSP for Baby GD.

Baby HB

Baby HB demonstrated learning in the MP, with a drastic increase in kicking during the Acquisition and Extinction phases (Fig. 8). He, however, showed no increase in in-target touching during the Acquisition phase of the TSP and only a slight increase in in-target touching during the Extinction phase (Fig. 8).

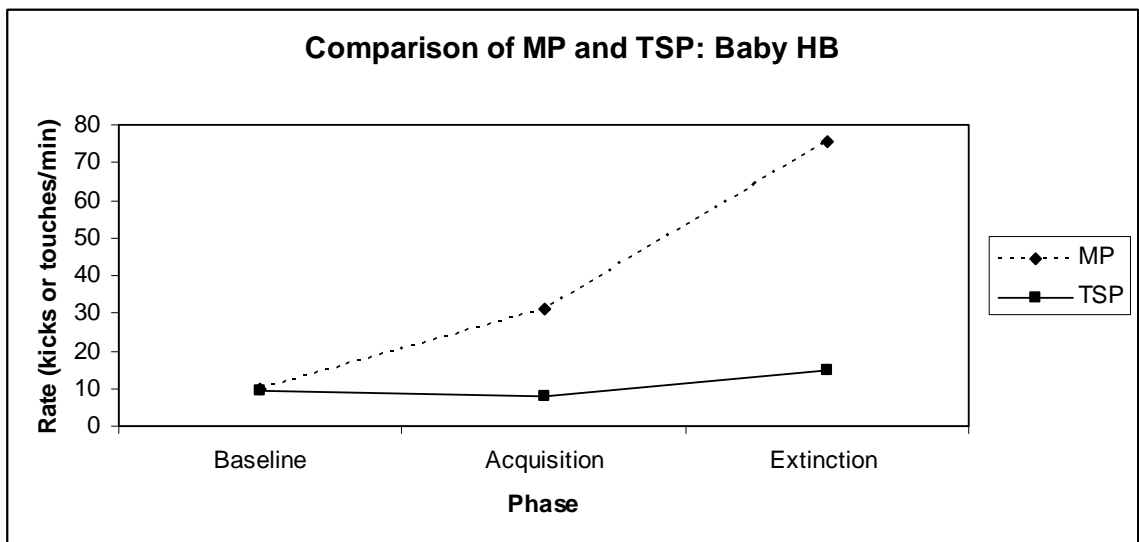


Figure 8. Comparison of MP and TSP for Baby HB.

Baby MES

Baby MES demonstrated learning in both the MP and the TSP, with an increase in kicking and touching rates during the Acquisition and Extinction phases as compared to Baseline (Fig. 9).

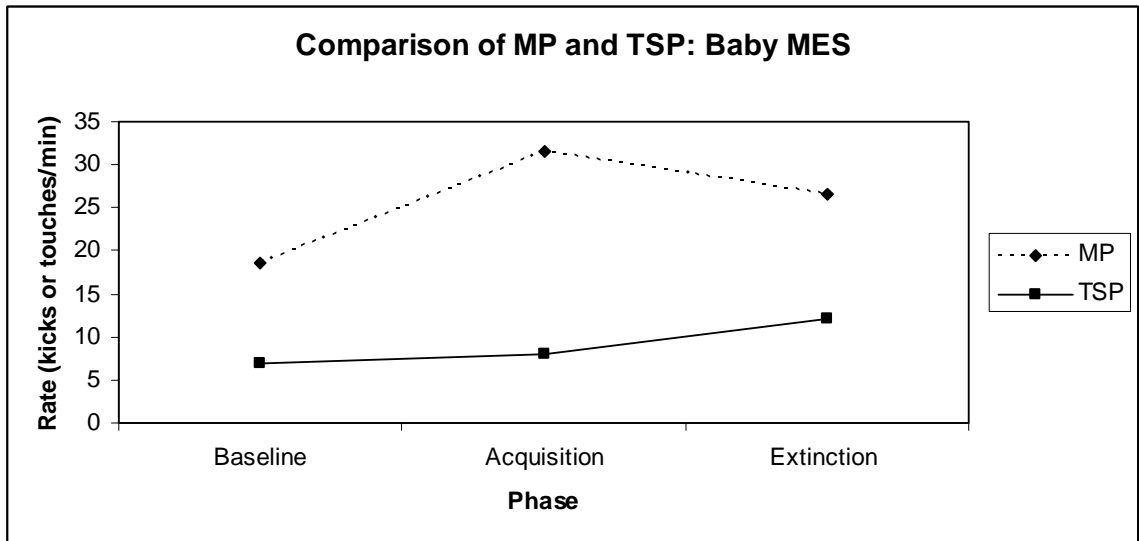


Figure 9. Comparison of MP and TSP for Baby MES.

Baby MS

Baby MS was only tested with the TSP due to him consistently rolling over. In the TSP, he demonstrated learning, with an increased in-target touching rate during Acquisition and Extinction as compared to Baseline (Fig. 10).

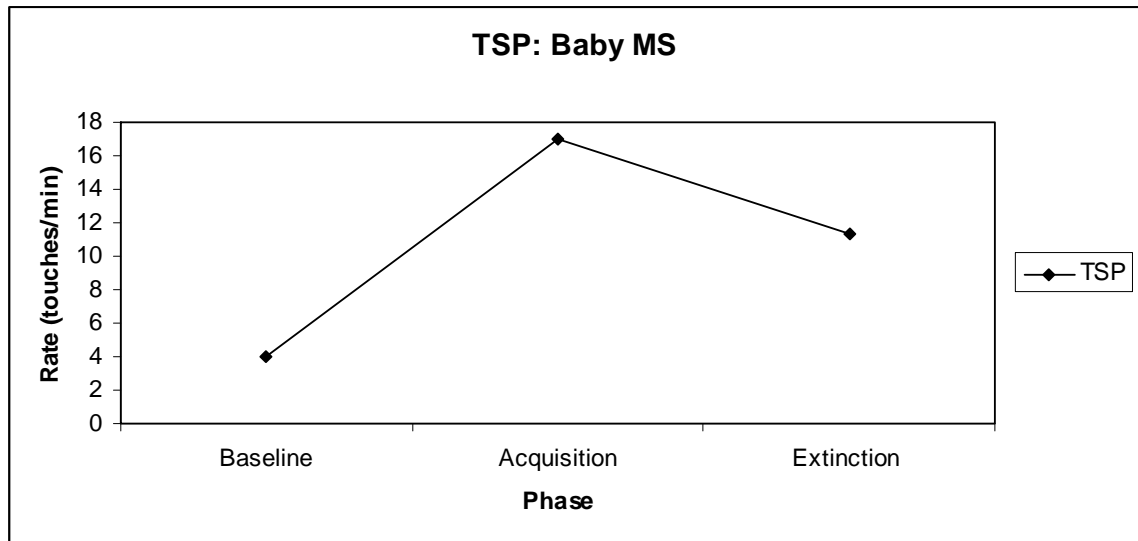


Figure 10. TSP data for Baby MS.

TSP: Manual Coding verses Program Data

The current computer program used in the TSP records all touches and whether or not they are in the target. The touch screen and program, however, were made to only recognize one touch, the first touch, at a time. As a result, many in-target touches were not counted in the computer program because an out-of-target touch occurred simultaneously. Because of this problem, we also coded the videos manually, but the infant did not receive reinforcement for all in-target touches if the program did not register a touch. The ratio between computer-recorded touches and behavior coding were similar, but the magnitude was not (Fig. 11).

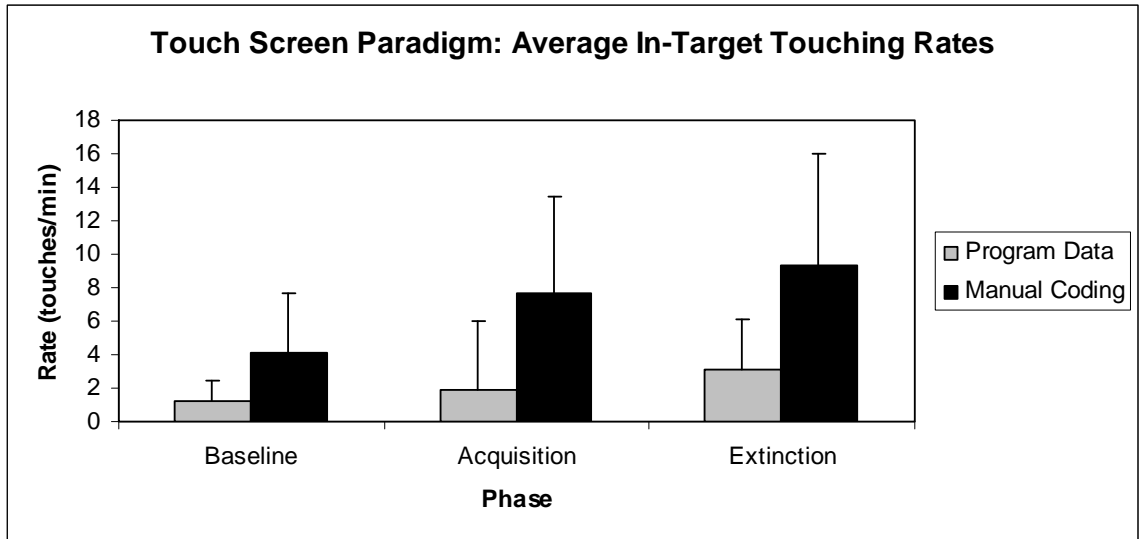


Figure 11. Comparison of program data and manual coding in the TSP.

Discussion

In summary, as a group, the infants demonstrated learning in both the MP and the TSP (Fig. 4). Individually, all infants demonstrated learning during the MP and four demonstrated learning during the TSP (Figs. 5, 6, 7, 8, 9, 10). We determined that learning occurred by comparing the rate of right-leg kicks or in-target touches during Acquisition and Extinction to Baseline. For the MP, all infants tested showed an increased rate of kicking during Acquisition as compared to Baseline, averaging an increase of 1.85 fold (Fig. 4). All infants tested in the Extinction phase of the MP showed an increased kicking rate during Extinction as compared to Baseline, averaging an increase of 3.04 fold (Fig. 4). As such, the Acquisition and Extinction ratios were greater than 1.5 for the MP, indicating that the infants, as a group, learned. The increase in kicking rate demonstrates that the infant learned the association between kicking with the right foot and mobile movement in a similar magnitude to previous research (Heathcock et al., 2004). On average, the group tested showed an increase in kicking rate during

Acquisition and then an additional increase during Extinction as compared to Baseline (Fig. 4). We expected this trend based on the principles of operant conditioning and the expected Extinction burst.

In the TSP with manual coding, three out of six infants showed an increase in in-target touching rate for Acquisition as compared to Baseline, averaging an increase of 1.86 fold (Figs. 4, 5, 6, 7, 8, 9, 10). Four out of six infants demonstrated an increase in in-target touching rate during Extinction as compared to Baseline, averaging an increase of 2.28 fold (Fig. 4). As such, the Acquisition and Extinction ratios were greater than 1.5 for the TSP, indicating that the infants, as a group, learned in this new paradigm. An increase in touching rate as compared to Baseline in either the Acquisition or Extinction phases indicates learning the cause-and-effect relationship. On average, in-target touching rates increased from Baseline to Acquisition to Extinction, which was expected based on the principles of operant conditioning.

We aimed to evaluate a program that counts the number of in-target touches as well as provide reinforcement for all in-target touches during the TSP. The discrepancy between the program data and manual coding data, however, indicates that the program did not count all in-target touches and that the infants did not receive reinforcement for all in-target touches (Fig. 11). This information significantly decreases the accuracy of the current methods used in the TSP in evaluating infant learning. Although the pattern of in-target touches was accurately assessed over the 3 time periods, the magnitude was not and so, the infants received inconsistent reinforcement, which likely affects their ability to learn the association (Fig. 11).

For the TSP, infants tended to choose one foot with which to touch the target and keep the other foot in place. During the MP, however, infants tended to kick about the same number of times with each leg. This qualitative analysis could show a difference between spontaneous infant behavior and end-point controlled behavior.

Strengths

The TSP did show a significant increase in in-target touching rates between Baseline and Extinction phases, indicating that it may accurately assess infant learning. In addition, the Extinction and Acquisition ratios were greater than 1.5, indicating learning occurred. The current TSP program does determine the correct pattern of in-target touches and follows the same pattern as MP testing, indicating it may be effective in testing learning. In addition, the TSP shows that infants can control movement to touch a specific target in 2D space. The computer program used in the TSP gives x,y coordinates of on-screen touches, which could be a future indication of learning and motor control. The data given by the computer program can be easily and quickly analyzed, whereas MP data cannot. In the future, the TSP, therefore, could be used by a physician or therapist to test infant learning quickly. The TSP could potentially be used on an individual level, not just a group level, for diagnosis in a clinical setting, whereas the MP only measures learning on a group level.

Limitations

Since six infants were tested, we are unable to make general conclusions about the effectiveness of the TSP. The discrepancy between manual coding and program data is also limiting in that infants did not receive reinforcement for all in-target touches and in

addition, did not get credit for touches in the program data. Therefore, the Extinction to Baseline ratio may be higher in future studies.

Future Research:

Before we test more infants using the TSP, we must fix the discrepancies between the program data and manual coding. With the current computer program, infants are not getting deserved reinforcement or credit for in-target touches. Ideally, a physician or therapist could use the TSP quickly and easily in a clinical setting in order to test an infant's cognitive ability. With the MP, this cannot be done because the data analysis process is long. If the computer program is fixed, however, data for the TSP would be immediate and could be analyzed quickly. In the future, we aim to perform the TSP on additional full-term and preterm infants as well as other populations of infants at risk for delay such as infants at risk for autism, infants with spina bifida, and infants at risk for cerebral palsy. Our ultimate goal is to determine if preterm infants' poor performance in the mobile paradigm is due to an inability to learn and remember cause-and-effect relationships or if it is due to problems in underlying motor skills.

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